Relationships between fish length and otolith length for nine teleost fish species from the Mediterranean basin, Kerguelen Islands, and Pacific Ocean

by

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ABSTRACT. - The relationship between fish size and otolith size was established for nine species from different geographical areas, the Mediterranean basin, Kerguelen Islands and the tropical Pacific Ocean. For all species, a significant linear relationship was found between fish size and otolith size. However, the 'lake ecotype' of the brown trout (*Salmo trutta fario*) from Kerguelen did not show such relationship, contrary to the two other 'ecotypes' from rivers and mixed biotopes. The reasons for such a pattern remain unknown. For a given species, comparisons of slopes of the relationship and Y-coordinate at the origin revealed differences according to studied sites or individual fish size. This suggests an influence of environmental and/or ontogenetic factors on the parameters of the relationship between fish size and otolith size.

RÉSUMÉ. - Relations entre la taille du poisson et celle des otolithes chez neuf espèces de téléostéens du bassin méditerranéen, des îles Kerguelen, et de l'océan Pacifique.

La relation entre la taille du poisson et celle de l'otolithe a été établie pour neuf espèces de téléostéens capturés dans le bassin méditerranéen, aux îles Kerguelen et dans le Pacifique tropical. Pour toutes les espèces étudiées, il existe une relation linéaire significative entre la taille du poisson et celle de l'otolithe. Toutefois, pour la truite fario (*Salmo trutta fario*), l'écotype présent dans les lacs des Kerguelen ne montre pas cette relation, à la différence des écotypes présents dans les rivières et dans les milieux 'mixtes'. Les raisons de cette absence de relation sont inconnues. D'une façon générale, des tests de comparaison de pente et de différence d'ordonnée à l'origine ont révélé qu'il existait, pour une espèce donnée, des différences selon les sites de prélèvement et/ou la taille des individus, ce qui suggère un effet des facteurs environnementaux et ontogénétiques sur les paramètres de la relation entre la taille du poisson et celle de l'otolithe.

Key words. - Lutjanidae - Mullidae - Salmonidae - Serranidae - Soleidae - Fish size - Otolith size.

Teleost fish have three pairs of otoliths: *sagittae*, *asterisci* and *lapilli*. Otoliths are mineral inert components made of calcium carbonate ($CaCO_3$), without any dissolution or resorption (Campana, 1999). They are located within the inner ear where they contribute to several physiological processes, such as audition, mecano-reception and equilibration (Popper and Combs, 1980) which allow fishes to achieve a better perception of their own environment. The otoliths register life history traits of individuals (age, reproduction, migration, etc.) and could be considered as "black-boxes" (Lecomte-Finiger, 1999). Otoliths are used in numerous biological and ecological studies (Campana, 2005) : species identification (L'Abée-Lund, 1988), age assessment (Cardinale *et al.,* 2004), individual growth (Baillon, 1992), stocks assessment (Friendland and Reddin, 1994; Tracey *et al.,* 2006; Gonzalez-Salas and Lenfant, 2007), and determination of the diet of predatory fishes (Barrett and Furness, 1990; Martucci *et al.,* 1993; Velando and Freire, 1999; Furness and Tasker, 2000; Lilliendahl and Solmundsson, 2006).

During the last 70 years, several studies evidenced that otoliths and fish size could be related by two types of relations: curvilinear (Fry, 1943) and, mainly, linear relationships (Trout, 1954; Templemann and Squires, 1956). The present study focus on such relationships for species coming from the tropical Pacific Ocean for *Cephalopholis argus, Lutjanus fulvus* and *L. kasmira,* the temperate Mediterranean basin for *Mullus barbatus, M. barbatus ponticus, M. surmuletus* and *Solea solea,* and the Kerguelen Islands in the sub-

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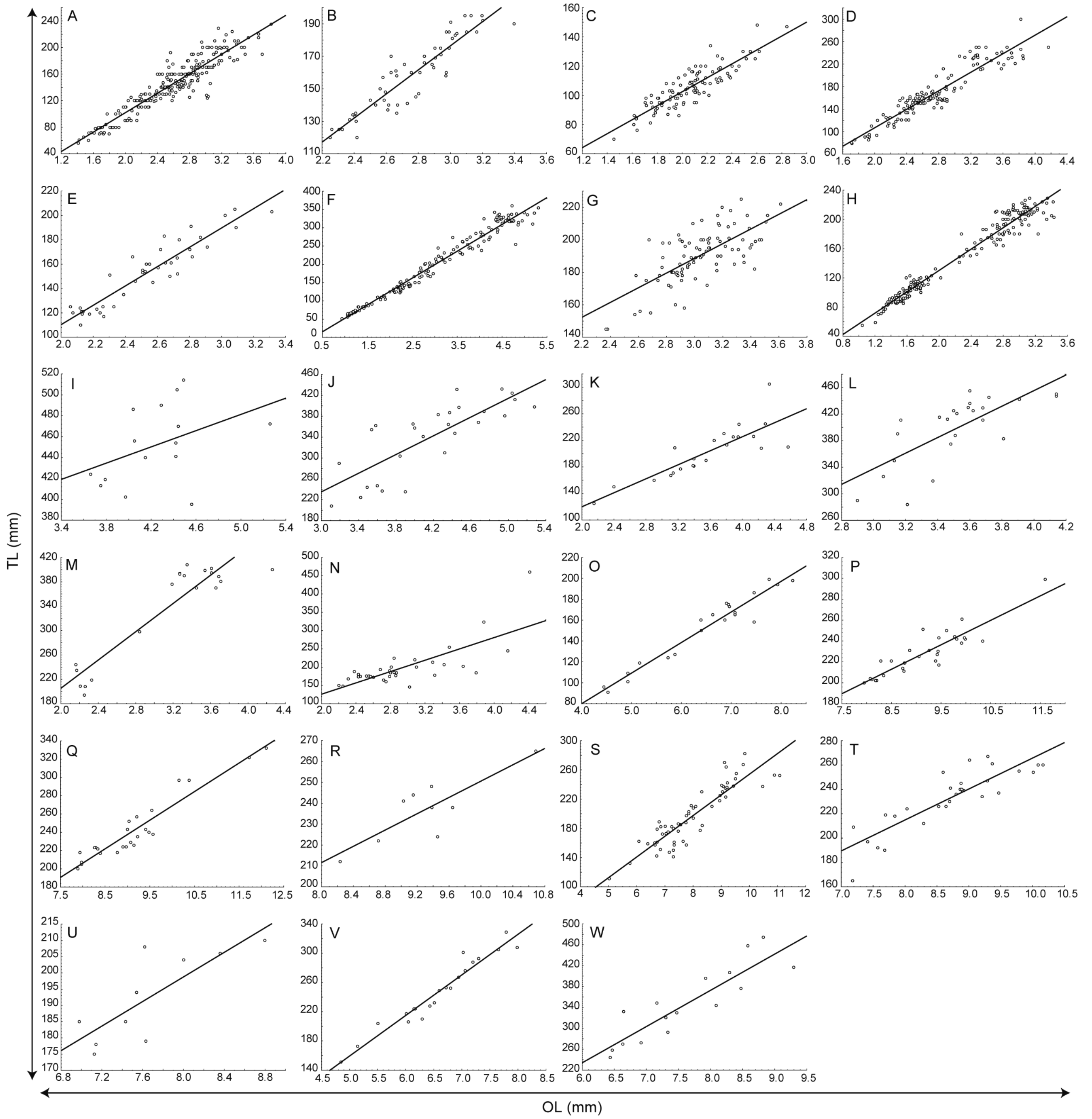

Figure 1. - Linear regression between fish size (TL, mm) and otolith size (Lo, mm) for the studied species from the various sites mentioned in table I. **A**: *Mullus barbatus* from NW Mediterranean Sea; **B**: *Mullus barbatus* from Aegean Sea; **C**: *Mullus barbatus ponticus* from Black Sea; **D**: *Mullus surmuletus* from NW Mediterranean Sea; **E**: *Mullus surmuletus* from Aegean Sea; **F**: *Solea solea* from NW Mediterranean Sea; **G**: *Solea solea* from Thau Pond; **H**: *Solea solea* from Mauguio pond; **I**: Kerguelen Islands, lake ecotype of *Salmo trutta fario*; **J**: Kerguelen Islands, mixed ecotype of *Salmo trutta fario*; **K**: Kerguelen Islands, river ecotype of *Salmo trutta fario*; **L**: Kerguelen Islands, lake ecotype of *Salvelinus fontinalis*; **M**: Kerguelen Islands, mixed ecotype of *Salvelinus fontinalis*; **N**: Kerguelen Islands, river ecotype of *Salvelinus fontinalis*; **O**: Medium-sized individual of *Lutjanus fulvus* from Moorea; **P**: Large-sized individual of *Lutjanus fulvus* from Moorea; **Q**: Large-sized individual of *Lutjanus fulvus* from Hawaii; **R**: Large-sized individual of *Lutjanus fulvus* from New-Caledonia; **S**: *Lutjanus kasmira* from Moorea; **T**: *Lutjanus kasmira* from Hawaii; **U**: *Lutjanus kasmira* from Fiji; **V**: *Cephalopholis argus* from Moorea; and **W**: *Cephalopholis argus* from Hawaii.

Antarctic region of the Indian Ocean (*Salmo trutta fario* and *Salvelinus fontinalis*). Such kind of information would be very useful especially for researchers studying the diet of top predators, such as large fish or seabirds, for which fish oto-

liths are important tools in the identification of prey species consumed. Their importance increases when the prey is partially or totally digested.

MATERIALS AND METHODS

Sampling sites

Goatfishes (*Mullus barbatus* and *M. surmuletus*, Mullidae) were caught in several stations in the NW Mediterranean, mostly within the Gulf of Lions (Bautista-Vega, 2008) and in the Aegean Sea, around the island of Lesvos (Mérigot *et al.*, 2006). Samples of *Mullus barbatus ponticus* were caught along the Romanian coasts, Black Sea (Banaru and Harmelin-Vivien, 2007). Individuals of *Solea solea* (Soleidae) came from the Gulf of Lions and from two coastal lagoons, Thau and Mauguio, NW Mediterranean (Mérigot *et al.*, 2007). Samples of the brown trout (*Salmo trutta fario*) and the brook trout (*Salvelinus fontinalis*) (Salmonidae) were caught in three freshwater biotopes in the Kerguelen Islands, southern Indian Ocean (lakes, rivers and 'mixed' biotopes) (Morat *et al.*, 2008). Finally, individuals of *Cephalopholis argus* (Serranidae), *Lutjanus fulvus* and *L. kasmira* (Lutjanidae) were caught in Moorea, French Polynesia and in the Hawaiian archipelago. In addition, individuals of *L. fulvus* were also caught in New-Caledonia, whereas those of *L. kasmira* also came from Fiji.

Morphometry

Each fish was measured to the nearest mm (TL). Both left and right *sagittae* of all individuals were extracted (total of 1378 individuals, *i.e.*, 2756 otoliths), cleaned with distilled water, and stored dry in tubes. Each *sagittae*, systematically placed with the *sulcus acusticus* oriented through the observer, was examined under a stereomicroscope (Leica Wild M8 or Leica MZ16) fitted with a numerical camera (Mediacybernetic® evolution LS color) linked to a computer. Numerical images were then acquired using the software Visilog 6.1 which allowed the measuring of the otolith length (Lo) to the nearest 0.1 mm. The most contrasted possible image obtained with the help of an episcopic light through optical fibres which enable us to optimise the direction and

Table I. - Relationships between total length (TL, mm) and otolith size (Lo, mm) for the studied species from the various sites, and for (A) all sizes pooled together, or for medium- (M) or large-sized (L) individuals. N = number of fish. Statistical significance : *** = $p < 0.0001$, ** = $p < 0.001$, * = $p < 0.05$, ns = non significant. *[Régression linéaire entre les longueurs totales (TL, en mm) et la taille des otolithes (Lo) des espèces étudiées dans les différents sites, et (A) pour l'ensemble des tailles individuelles, ou pour les poissons de tailles moyenne (M) ou grande (L). N = nombre de poissons. Signification statistique : *** = p < 0.0001, ** = p < 0.001, * = p < 0.05, ns = non significatif.]*

Species	Site	Size range (mm, TL)	N	Relationships	R^2	p
Mullus barbatus barbatus	NW Mediterranean Sea (A)	56-235	235	TL = 73.20 * Lo – 44.48	0.862	***
	Aegean sea (A)	120-195	55	TL = 74.11 * Lo – 45.88	0.849	***
Mullus barbatus ponticus	Black Sea (A)	70-148	103	TL = 47.73 * Lo + 6.93	0.756	***
Mullus surmuletus	NW Mediterranean Sea (A)	79-300	134	TL = 82.33 * Lo – 57.87	0.870	***
	Aegean Sea (A)	110-205	41	TL = 79.30 * Lo – 48.25	0.873	***
Solea solea	NW Mediterranean Sea (A)	51-360	161	TL = 73.40 * Lo – 21.28	0.971	**
	Thau Pond (A)	145-225	93	TL = 45.15 * Lo + 53.17	0.449	**
	Mauguio Pond (A)	55-229	191	TL = 73.05 * Lo – 15.92	0.958	**
Salmo trutta fario	Lake "Ecotype" (A)	385-514	15	TL = 38.89 * Lo + 286.90	0.178	ns
	Mixed "Ecotype" (A)	208-432	27	TL = 89.58 * Lo – 33.64	0.634	***
	River "Ecotype" (A)	125-305	22	TL = 52.63 * Lo + 14.84	0.702	***
Salvelinus fontinalis	Lake "Ecotype" (A)	284-455	24	TL = 117.60 * Lo – 15.06	0.540	***
	Mixed "Ecotype" (A)	194-408	20	TL = 116.00 * Lo – 26.77	0.858	***
	River "Ecotype" (A)	146-460	35	TL = 77.50 * Lo – 29.08	0.551	***
Lutjanus fulvus	Moorea (M)	91-199	21	TL = 29.29 * Lo – 37.22	0.942	***
	Moorea (L)	200-299	30	TL = 23.43 * Lo + 13.82	0.809	***
	Hawaii (L)	200-332	25	TL = 31.29 * Lo – 44.11	0.898	***
	New Caledonia (L)	212-265	9	TL = 19.51 * Lo + 55.46	0.700	*
Lutjanus kasmira	Moorea (A)	111-282	60	TL = 28.29 * Lo – 28.87	0.806	***
	Hawaii (A)	165-267	30	TL = 25.41 * Lo + 11.57	0.750	***
	Fiji (A)	175-210	10	TL = 18.92 * Lo + 47.39	0.639	*
Cephalopholis argus	Moorea (A)	151-329	21	TL = 55.48 * Lo – 118.00	0.940	***
	Hawaii (A)	244-474	16	TL = 69.37 * Lo – 182.20	0.792	***

intensity of light.

Data analysis

The relationships between fish length (TL, mm) and otolith length (Lo, mm) for both *sagittae* for the different species and the different sites were calculated through linear regressions. For each *sagittae (i.e.*, left and right), we tested differences of the slope of these linear regressions with a Z-test (Zar, 1999) among different species and among the same species at the different sampled sites. We also compared the Y-coordinate at the origin (*i.e.*, the 'b' of the linear regression y = ax + b) with a F-test when linear regression slopes were identical (Zar, 1999). No significant difference was evidenced between relationships obtained with left and right *sagittae* for all species and sites. Thus, we decided to hereafter use the most abundant *sagittae* as some were broken during extraction.

RESULTS AND DISCUSSION

The different relationships between fish length and otolith length are shown in table I and figure 1. Comparisons of slopes of fish length *vs*. otolith length relationships for *Mullus barbatus barbatus* caught in the NW Mediterranean and in the Aegean Sea did not displayed any significant difference, but the slopes of the relationships for both populations were statistically different from the slope obtained for the subspecies from the Black Sea (*M. barbatus ponticus*) (F = 23.35; p < 0.001, F = 30.70; p < 0.0001 for the NW Mediterranean and the Aegean populations, respectively). No significant difference was found for *M. surmuletus* from the two studied sites, *i.e.*, the NW Mediterranean and the Aegean Sea. For *Solea solea*, the size-range of individuals sampled was different between sites (Tab. I), and the comparison of slopes was thus made only for fish of size 141 < TL < 225 mm. It revealed a significant difference between the Thau lagoon and the two other sites, *i.e.,* the Mauguio lagoon (F = 4.71; p = 0.030) and the NW Mediterranean (F = 15.66; p < 0.001).

The comparison of slopes realized for *Salvelinus fontinalis* from Kerguelen Islands revealed no difference between the lake and 'mixed biotopes' populations, but evidenced a significant difference with the river population (F = 8.71 ; p = 0.004). For *Salmo trutta fario*, and due to the non significance of the fish length *vs*. otolith length relationship for the lake population, the comparison of slopes was made only between the river and 'mixed biotopes' populations, and a significant difference was found (F = 4.97; p = 0.031).

Samples of *Lutjanus fulvus* from New Caledonia did not displayed any difference of slope of the fish length *vs* otolith length relationship with those of the other sites. Medium-sized (96-200 mm) and large individuals (> 200 mm) from Moorea however had significantly different slopes (F = 4.63; p = 0.037). In addition, the slopes of the fish length *vs*. otolith length relationship of large individuals of this species displayed significant differences between sites of Moorea and Hawaii (F = 6.45; p = 0.014). Samples of *L. kasmira* and *Cephalopholis argus* did not shown any significant difference of slopes of the fish length *vs* otolith length relationships between sites.

Irrespective of the geographical area, i.e. sub-Antarctic, temperate or tropical, and the fish family, our different results evidenced clear linear relationships between fish length and the length of its otolith, thus reinforcing this view already shown since the 50s'. However, the case of *Salmo trutta fario* from Kerguelen' lakes is surprising. This non-significant relationship could reflect the presence of fish having different origins as suggested by Ayllon *et al.* (2006). In fact, *S. trutta fario* has been introduced in Kerguelen from two different lineages (wild Polish and domestic commercial European populations) and have widely colonized the hydrographic systems (Duchêne, 1989; Duhamel *et al.*, 2005). Our samples could present also a mix of fish from different populations. But we also highlighted differences of slopes according to sites for some species, and in other cases differences between Y-coordinate at the origin of the slope, but not for the slope itself. This latter case was well illustrated by large individuals of *Lutjanus kasmira* between Moorea and Hawaii (F = 6.06; p = 0.017), and between Hawaii and Fiji (F = 8.91; p = 0.005). Similar results were found for *L. fulvus* between individuals from New-Caledonia and Hawaii (F = 4.74; p = 0.037), for *Cephalopholis argus* between Hawaii and Moorea (F = 13.88; p < 0,001) and for *Solea solea* between individuals from the NW Mediterranean and those of Mauguio coastal lagoon (F = 3.64; p = 0.004). Both kinds of results suggest possible differences in environmental conditions, and/or variations in the sensibility of fish to these conditions encountered during the fish life history and/or from different sites (and of course between different species). These can be differences in diet, ontogenetic spatial shift within a given habitat, or migration between coastal lagoons and open sea or along a depth gradient when fish size increases (Mérigot *et al.*, 2007; Bautista-Vega, 2008). As already stated, such kind of linear relationship would be very useful in studying the diet of top predators, such as large fish or seabirds, for which fish otoliths are the unique possibility to identify the species consumed. Thus, it provides a convenient tool to assess the consumed biomass and then allows the assessment of the specific impact of these predators on prey stock.

REFERENCES

AYLLON F., DAVAINE P., BEALL E. & E. GARCIA-VAZQUEZ, 2006. - Dispersal and rapid evolution in brown trout colonizing virgin Subantarctic ecosystems. *J. Evol. Biol*., 19: 1352-1358.

BAILLON N., 1992. - Otolithométrie : revue et problèmes. *In*: Coll. Intern. Tissus durs et âge individuel des vertébrés (Baglinière J.L., Castanet J., Conand F. & F. Meunier, eds), pp. 21-52. Bondy (France): Orstom/Inra.

BANARU D. & M. HARMELIN-VIVIEN, 2007. - Variations spatio-temporelles de la signature en isotopes stables ($\delta^{13}C$ et $\delta^{15}N$) des eaux du Danube et des communautés marines sur les côtes roumaines de la mer Noire. *Cybium*, 31(2): 167-174.

BARRETT R.T. & R.W. FURNESS, 1990. - The prey and diving depths of seabirds on Hornøy, North Norway after a decrease in the Barents Sea capelin stocks. *Ornis Scand*., 21: 179-186.

BAUTISTA-VEGA A.A., 2008. - Étude des réseaux trophiques aboutissant aux rougets méditerranéens (*Mullus barbatus* et *M. surmuletus*) par utilisation des isotopes stables. *Cybium*, 32(3): 264.

CAMPANA S.E., 1999. - Chemistry and composition of fish otoliths: Pathways, mechanisms and applications. *Mar. Ecol. Prog. Ser*., 188: 263-297.

CAMPANA S.E., 2005. - Otolith science entering the 21st century. *Mar. Freshw. Res*., 56: 485-495.

CARDINALE M., DOERING-ARJES P., KASTOWSKY M. & H. MOSEGAARD, 2004. - Effects of sex, stock and environment on the shape of known-age Atlantic cod (*Gadus morhua*) otoliths. *Can. J. Fish. Aquat. Sci*., 61: 158-167.

DUCHÊNE J.-C., 1989. - Kerguelen : Recherche au Bout du Monde. Territoire des terres australes et antarctiques françaises, Mission recherche.

DUHAMEL G., GASCO N. & P. DAVAINE, 2005. - Poissons des Îles Kerguelen et Crozet. Guide régional de l'Océan Austral. 419 p. Paris: Muséum national d'Histoire naturelle.

FRIENDLAND K.D. & D.G. REDDIN, 1994. - Use of otolith morphology in stock discrimination of Atlantic salmon (*Salmo salar*). *Can. J. Fish. Aquat. Sci*., 51: 91-98.

FRY F.E.J., 1943. - A method for the calculation of the growth of fishes from scale measurement. *Publ. Ont. Fish. Res. Lab*., 61: 5-18.

FURNESS R.W. & M.L. TASKER, 2000. - Seabird-fishery interactions: Quantifying the sensitivity of seabirds to reductions in sandeel abundance, and identification of key areas for sensitive seabirds in the North Sea. *Mar. Ecol. Prog. Ser*., 202: 253-264.

GONZALEZ-SALAS C. & P. LENFANT, 2007. - Interannual variability and intraannual stability of the otolith shape in European anchovy *Engraulis encrasicolus* (L.) in the Bay of Biscay. *J. Fish Biol*., 70: 35-49.

L'ABÉE-LUND J.H., 1988. - Otolith shape discriminates between juvenile Atlantic salmon, *Salmo salar*, and brown trout, *Salmo trutta*. *J. Fish Biol*., 33: 899-903.

LECOMTE-FINIGER R., 1999. - L'otolithe : la "boîte noire" des Téléostéens. *Ann. Biol*., 38: 107-122.

LILLIENDAHL K. & J. SOLMUNDSSON, 2006. - Feeding ecology of sympatric European shags *Phalacrocorax aristotelis* and great cormorants *P. carbo* in Iceland. *Mar. Biol*., 149: 979-990.

MARTUCCI O., PIETRELLI L. & C. CONSIGLIO, 1993. - Fish otoliths as indicators of the cormorant *Phalacrocorax carbo* diet (Aves, Pelecaniformes). *Bull. Zool*., 60: 393-396.

MÉRIGOT B., BATJAKAS I.E. & Y. LETOURNEUR, 2006. - Fish community structure of two Greek close gulfs (Lesvos Island, Aegean Sea). *Cybium*, 30(1): 79-81.

MÉRIGOT B., LETOURNEUR Y. & R. LECOMTE-FINIGER, 2007. - Characterization of local populations of the common sole *Solea solea* (Pisces, Soleidae) in the NW Mediterranean through otolith morphometrics and shape analysis. *Mar. Biol*., 151: 997-1008.

MORAT F., BETOULLE S., ROBERT M., THAILLY A.F., BIAGIANTI-RISBOURG S. & R. LECOMTE-FINIGER, 2008. - What can otolith examination tell us about the level of perturbations of Salmonid fish from the Kerguelen Islands? *Ecol. Freshw. Fish*., in press. doi: 10.1111/j.1600-0633.2008.00313.x

POPPER A.N. & S. COMBS, 1980. - Auditory mechanisms in teleost fishes. *Am. Sci*., 68: 429-440.

TEMPLEMANN W. & H.J. SQUIRES, 1956. - Relationship of otolith lengths and weights in the haddock, *Melanogrammus aeglefinus* (L.), to the growth of the fish. *J. Fish. Res. Board Can*., 13: 467-487.

TRACEY S.R., LYLE J.M. & G. DUHAMEL, 2006. - Application of elliptical Fourier analysis of otolith form as a tool for stock identification. *Fish. Res*., 77: 138-147.

TROUT G.C., 1954. - Otolith growth of the Barents Sea cod. *P-V. Reun. Cons. Int. Explor. Mer*, 150: 297-299.

VELANDO A. & J. FREIRE, 1999. - Intercolony and seasonal differences in the breeding diet of European shags on the Galician coast (NW Spain). *Mar. Ecol. Prog. Ser*., 188: 225-236.

ZAR J.H., 1999. - Comparing simple linear regression equations. *In*: Biostatistical Analysis, 4th Edit. (Zar J.H., ed.), pp. 360-368. Upper Saddle River, NJ: Prentice-Hall.

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